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Abstract

HELICAL, FORCED-FLOW HEAT TRANSFER AND FLUID DYNAMICS IN SINGLE AND TWO PHASE SYSTEMS

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This paper investigates the influence of superimposed, rotational motion on forced-flow heat transfer and fluid dynamics in single and two-phase systems. Helical flow may be developed by forcing a fluid through a tube that contains a continuous, twisted divider or a helical guide vane located only at the tube wall. Under these circumstances the flow patterns are completely or partially constrained by flow guides. Helical flow may also be generated in a tube by forcing the fluid through tangencial entrance ducts. The resulting flow pattern is unconstrained, decaying rotational flow superimposed on a constant axial flow component.

A number of investigators have measured the heat transfer and fluid friction characteristics of gases and liquids under helical flow in tubes. In general, the heat transfer conductances and friction factors or pressure drops were found to increase with the magnitude of the rotational fluid flow component. The specific fluid velocity profiles and the magnitude of wall heat addition also influenced the experimental results. Two-phase or boiling heat transfer and fluid friction measurements for liquid metal and ordinary liquids under helical flow in tubes are also available. Again, heat transfer conductances and friction factors or pressure drops were found to increase with the magnitude of the rotational fluid flow component as was the case for single-phase flow; however, the functional variation is more complicated because of the various ways in which the two phases can distribute themselves in the tube.

Heat and momentum transfer in helical single-phase flow can be predicted by accounting for free and forced convection mechanisms which exist in the

curvilinear flow patterns. The free convection term for a given fluid is controlled by the acceleration field produced by the velocity field of the rotating fluid and the magnitude of the wall heat addition. The forced convection term in helical flow for a given fluid is defined by the turbulence level which normally is large because of the relatively large vectorial fluid velocities and geometrical turbulence promotion. In two-phase or boiling systems, the acceleration forces in helical flow control the spacial distribution of liquid films and droplets in boiler tubes and the corresponding heat transfer and fluid friction. In the low vapor quality region of a boiler, centrifugal forces in rotational flow force liquid to be located contiguous to the tube wall thereby yielding more effective heat transfer. In the high vapor quality fog flow region, the centrifugal forces increase the density of the liquid droplets in the vapor layers contiguous to the tube wall thereby significantly increasing the evaporative heat transfer in that important region. The frictional pressure drop in a tube under two-phase flow conditions can be estimated with the aid of idealized mathematical models if the phases are distributed in simple patterns. Fluid dynamical analyses have been made for constrained and unconstrained helical flow in tubes. The mathematical heat transfer and fluid dynamics models have been used to predict performance of helical single and two-phase flow systems. These results are in general agreement with the experimental behavior.

It was found experimentally that the ratio of Stanton modulus to the friction factor for helical single and two-phase flow was not a unique function as in the case of linear single-phase flow. It is believed that a wide range of ratios are possible depending upon the character of the velocity structure of the rotational flow, the phase distribution, turbulence promotion and the wall heat addition. Some aspects of the variation in the heat transfer to pumping power ratio can be explained analytically.